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ELECTROMAGNETIC HEATING IN A MODEL OF FROZEN RED BLOOD CELLS

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The purpose of this study was to examine the feasibility of a dry method of thawing frozen human red blood cells using radio frequency energy. Human red blood cells are stored for long periods by using cryoprotective agents and freezing at -80°C. Current practice is to thaw the frozen cells in a warm water bath before preparation for use. In the thawing process, a small precentage of units are contaminated by the water-borne bacteria. Evaluation of radio frequency energy deposition in a model of a standard blood bag was made using thermometric and thermographic dosimetry. The results of this study show the ability of a radio frequency coil irradiating system to produce uniform heating in a model blood bag. Further study is recommended to explore the development of a system that would quickly thaw multiple units of frozen red blood cells.

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SUMMARY PAGE

THE PROBLEM

Human red blood cells are stored for long periods by using cryoprotective agents and freezing at -80 ^{o}C. The current practice is to thaw the frozen cells in a warm water bath before preparation for use. In the thawing process, a small percentage of units are contaminated by water-borne bacteria. A dry method of thawing would eliminate the bacterial threat of the water bath. The purpose of this study was to examine the feasibility of a dry thawing method using radio frequency (RF) energy to eliminate the water-related sources of contamination.

FINDINGS

We evaluated RF energy deposition in a standard blood bag filled with room temperature muscle-equivalent material. Relatively uniform specific absorption rates (SARs) were observed in the major portion of the bag. Thermographic images corroborate the thermometric results.

RECOMMENDATIONS

The results of this study show the ability of an RF-coil irradiating system to produce uniform heating in a model blood bag. We recommend that further study be undertaken to explore the development of a system that would quickly thaw multiple units of frozen red blood cells.

INTRODUCTION

The storage period of packed red blood cells (pRBCs) can be extended considerably by freezing (1). In 1950, glycerol techniques were applied to the freezing of red blood cells, but frozen cells did not become clinically useful until the 1960s, after the development of effective techniques for removing glycerol (2). The current practice is to freeze preparations of pRBCs at -80 °C, then thaw them in a warm water bath at approximately 37 °C for 10 to 20 min before preparation for use (2). In the process, a small percentage of units are contaminated by bacteria (3). A dry thawing technique, using radio frequency (RF) energy, would eliminate the contamination by water baths. In vitro viability of microwave thawed pRBCs was studied at the Naval Ocean Systems Center, where survival of small volumes of microwave-thawed cells were comparable to those thawed in a warm water bath (4). In the same study, nonuniform heating was a problem that was partly solved by revolving individual samples during exposure and pulsing the microwaves on and off until thawing was completed (4).

The purpose of the present study was to determine whether a method using RF energy from a helical coil system would produce uniform heating in a model of a standard pRBC bag. The extent of this study was limited to a thermometric and thermographic dosimetry of RF-induced heating of the model.

MATERIALS AND METHODS

A standard, 800-ml (12 cm x 21 cm) primary polyvinylchloride (PVC) plastic collection bag (Fenwal #4R1242) was used for testing (Fig. 1). The bag was filled with 400 g of muscle-equivalent material consisting of 9.15% aluminum powder, 80.88% water, and 0.28% sodium chloride (5) to approximate the average weight and similar RF-absorption properties of glycerolized, frozen pRBCs. The cryopreservative pressing solution ("Glycerolyte," Travenol Laboratories, Inc.) typically contains glycerin, sodium lactate, and potassium chloride. Dielectric properties of a mixture of Glycerolyte and physiological saline (to approximate the normal pRBC concentration) were measured at 27.12 MHz using a coaxial probe and network analyzer system similar to that described by Stuchley and coworkers (6). The Glycerolyte mixture and the phantom material were very similar in electrical conductivity, but the dielectric constant of the phantom material was about twice that of the Glycerolyte/saline mixture due, mostly, to the low dielectric constant of glycerin relative to that of water. Although the distribution of heating in a solid, frozen pRBC sample would be difficult to measure, dosimetric analysis was readily accomplished using a collection bag filled with room temperature muscle-equivalent material. To characterize the distribution of energy deposition in the sample, a 16-point (four by four) measurement pattern was selected. The points were equally divided across the flat surface of the bag, and four measurements of RF-induced temperature rise were made at three depths for each point: top (3 mm), mid (14 mm), and bottom (21 mm).

A resonant helical coil was constructed similar to that used in previous studies at this laboratory (7,8). The resonant operating frequency (27.12 MHz) was selected to be an Industrial Scientific and Medical frequency. At that wavelength, the coil enclosed a single pRBC bag. The coil was 11 turns of 3/8 inch (OD) copper tubing over a 40-cm long length of 15-cm diameter

plastic pipe that had been heated and formed to an 18.5 x 10.5 cm oval shape as shown in Fig. 1. To match the impedance of the source and to provide coupling of the RF energy, a primary winding of 5.5 turns of 1/4 inch (OD) copper tubing was placed around the center of the main coil on lucite spacers. A balanced-to-unbalanced transformer (1-to-1 Balun) was placed between the RF source and the primary winding to decouple the coil from the unbalanced coaxial output of the transmitter. To reduce RF field intensities around the device, an aluminum foil shield, supported by a thin plastic form, was employed. Styrofoam blocks were used to support and center the coil within the shield. The sample bag was centered within the main coil in the same way. The effectiveness of the shield was measured with an electromagnetic radiation monitor (Narda model 8662 probe and 8616 instrument). With a power level of 100 W, RF power densities were 1 mW/cm^2 at a 15-cm distance on axis and less than 0.1 mW/cm^2 at a similar distance perpendicular to the coil axis.

A military URT-23B communications transmitter, operated on continuous wave (CW), was used as the RF source. Temperature measurements in the sample were made with a fast-response platinum temperature probe (Hewlett-Packard 8208A). Surface heating in the sample was studied qualitatively using a UTI Spectrotherm thermographic imager.

In a typical procedure, 16 temperatures were taken at a given depth before irradiation. The sample bag, contained in its standard cardboard storage container, was then placed in the center of the helical coil and irradiated for 120 s with the transmitter set for 100-W output power. The bag was then removed and temperatures were remeasured. Typically, the 16 post-irradiation measurements were completed within 3 min. To minimize the effects of heat diffusion during this period, each 16-measurement sequence was reversed. Each probe depth had four measurement sequences. The RF power applied to the coil and the irradiation time were selected to produce a linear temperature rise in the material. The sample was allowed to stabilize at least 24 h between measurement sessions. Temperature rise (T) data were used to calculate localized specific absorption rates (SARs) according to standard methodology (9).

RESULTS

Figure 2 shows the SARs obtained from the model. Relatively uniform SARs were observed within the measured grid for each depth. The somewhat lower values for the top (3 mm) location were possibly caused by surface cooling effects during the post-irradiation temperature measurements. The thermographic imaging results are shown in Fig. 3 where lighter shades indicate warmer temperatures. The sensitivity of the system was such that a light-to-dark transition accounted for a span of 4 ^{o}C. Figure 3 corroborates the thermometric results and indicates uniform heating at the surface of the major portion of the bag. Higher RF-induced heating is seen in a narrow region at the base of the bag and in the folded flap region where the model material was very thin. The base and flap region SARs were estimated to be about nine times higher than those in the remainder of the bag, based on approximate temperature rises observed in the thermographic image.

DISCUSSION

These results show the ability of an RF-coil irradiation system to produce relatively uniform heating in a pRBC bag containing biological material. For the 16 locations at which SAR was calculated at 3 depths, mean SAR ($\pm$ SD) was 30.1 $\pm$ 5.7 W/kg. This result predicts that most of the pRBC sample would be uniformly thawed.

Although the folded flap region and a small region along the edge opposite the flap showed much higher SAR, we feel that the consequences of this in terms of cell damage would be minimal for several reasons. First, the high-SAR regions account for an extremely small fraction of the total sample volume, that is, less than 0.5%. Second, the surface areas of the high-SAR regions are large relative to the volumes, which tends to limit RF-induced temperature rises. Third, we conducted several preliminary thawing tests using a frozen sample bag containing a 40/60 (saline/Glycerolyte) mixture and found that the heating in the high-SAR regions of the bag produced only a mild warmth to the touch after approximately 9 min of irradiation at 250 W, which was sufficient power to just barely melt a -80 ^{o}C sample. We surmise that the initially very cold sample temperature, combined with the geometrical features of the high-SAR regions, prevented those regions from reaching more than lukewarm temperatures.

Many improvements could be incorporated into the basic RF-coil irradiator to produce a practical device that is capable of thawing many pRBC units simultaneously. The multiple unit capability and the elimination of potential sample contamination from the warm water thawing procedure make further development of the system highly desirable.

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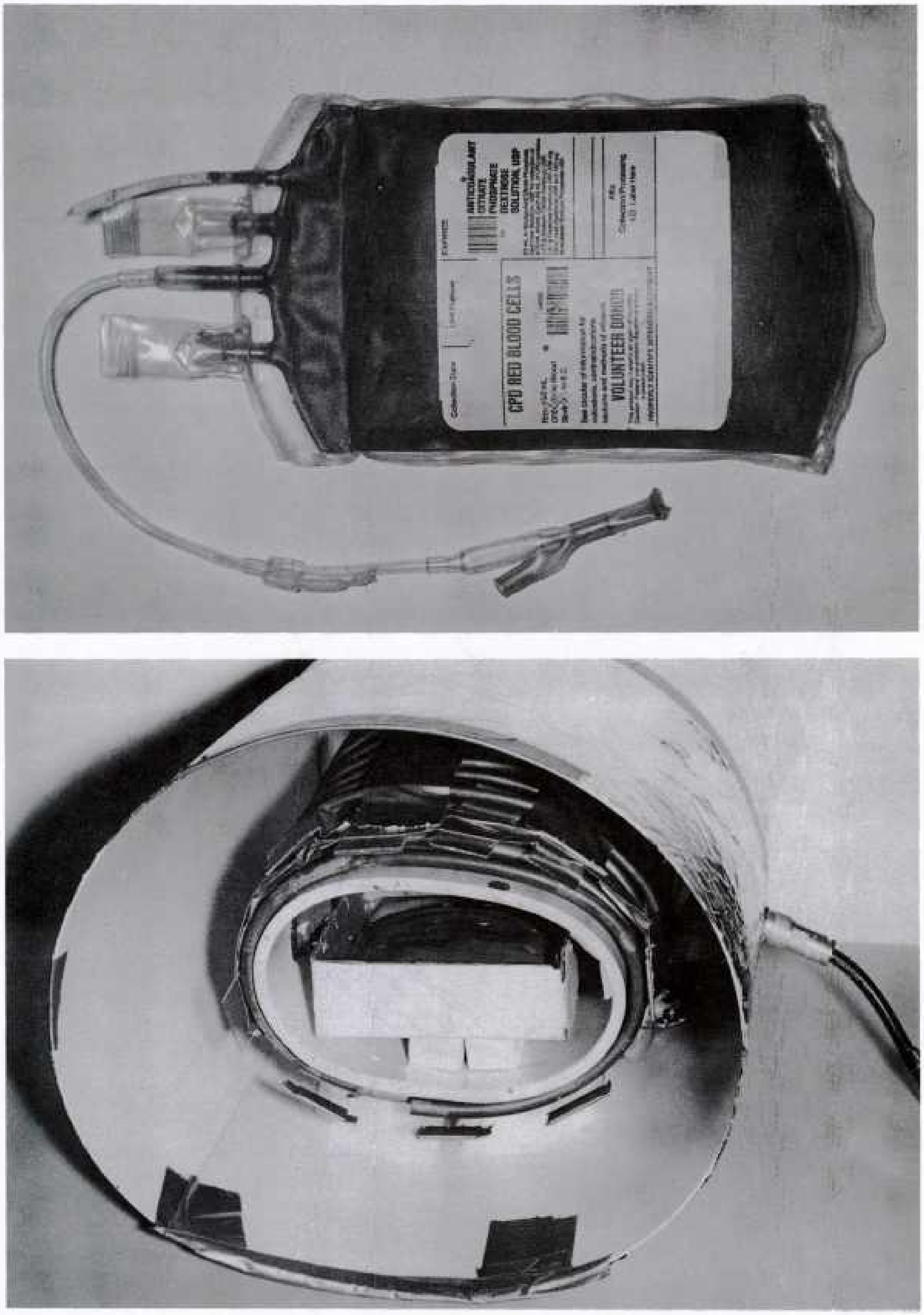

Figure 1. Top: Standard collection bag filled with muscle-equivalent material. Bottom: RF-coil irradiator with bag model in position.

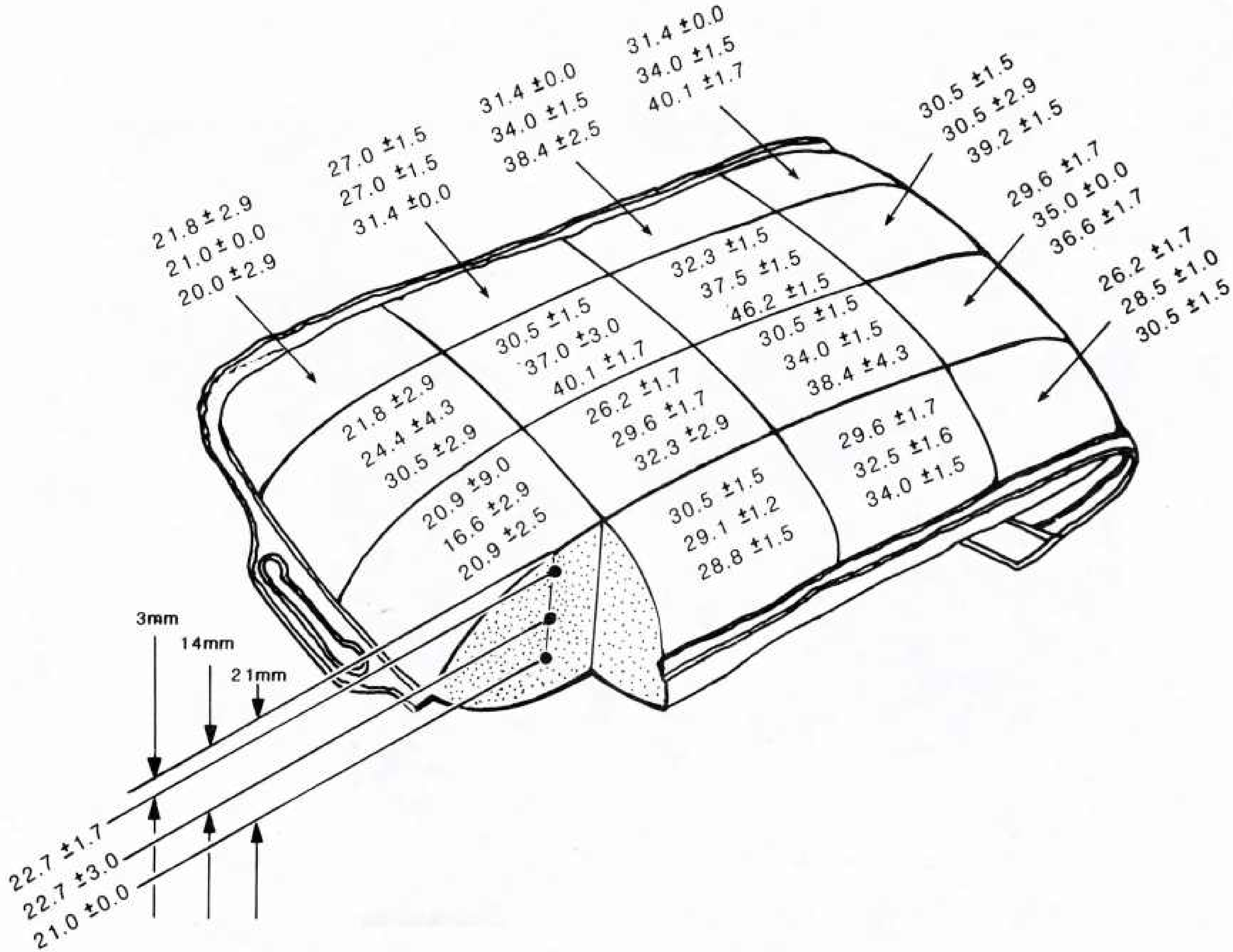

Figure 2. Mean SAR (± SD) for 16 locations and 3 depths of folded bag model.

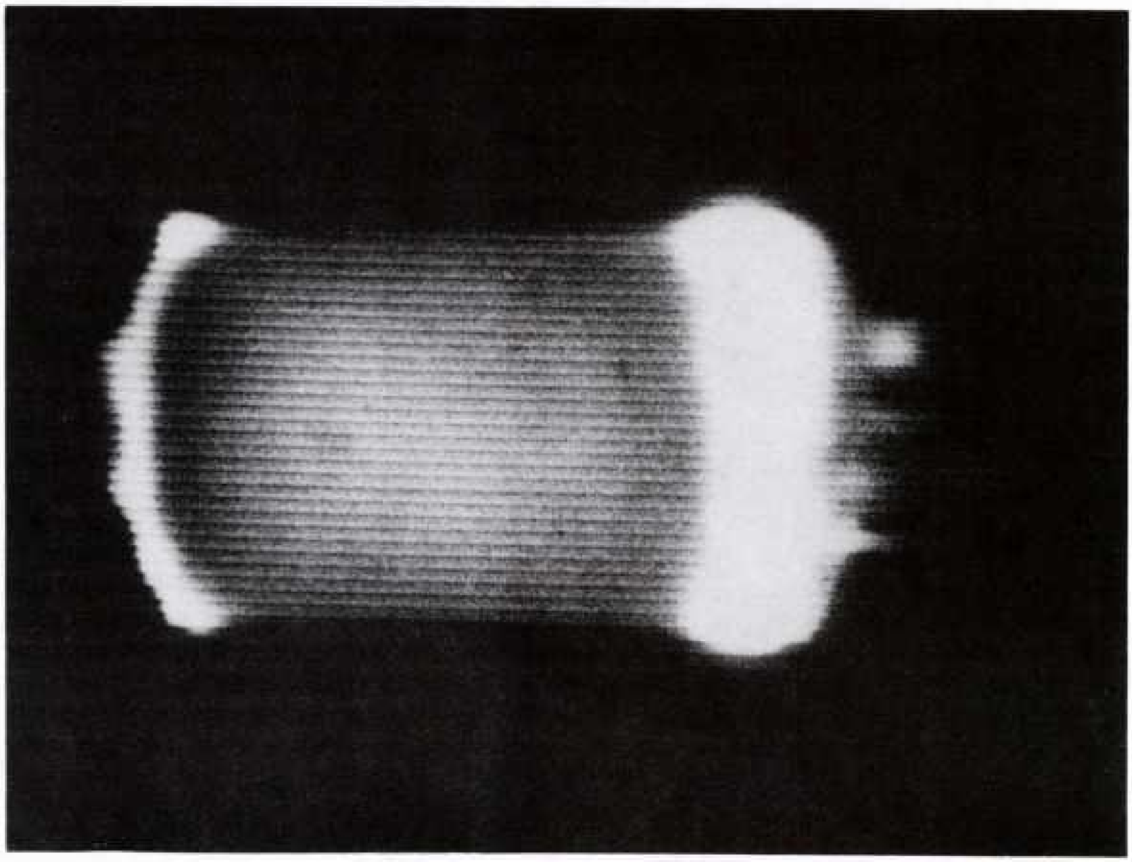

Figure 3. Thermographic image of RF-heated pRBC bag model.

Other Related NAMRL Publications

None are applicable.

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